4.0 ANALYSIS OF THE INCIDENT

4.1 DESIGN AND INSTALLATION DEFICIENCIES

The propane storage and handling system was installed at the farm in 1988. When the tank system was installed, Iowa law provided that the 1979 edition of the National Fire Protection Association's *Standard for the Storage and Handling of Liquefied Petroleum Gases* (NFPA 58) governed the installation.[19] As discussed below, the propane system at the farm did not comply with NFPA 58 in two significant respects that contributed to the incident: Aboveground piping was not protected from potential damage from vehicles, and the liquid propane outlet pipe downstream from an excess flow valve was too narrow in diameter.

4.1.1 Lack of Protection from Vehicular Damage

Section 3120(c) of NFPA 58 provided as follows: "Where physical damage to LP-Gas containers, or systems of which they are a part, from vehicles is a possibility, precautions against such damage shall be taken."[20] In addition, section 3165 of NFPA 58 stated that "[a]boveground piping shall be well supported and protected against physical damage."[21]

The area where the tank and its aboveground pipes[22] were located was bordered on the south by a public road and on the east and west by gravel driveways (see Figure 1). Fueling truck deliveries occurred as often as every week during severe winter months. In addition, there was

[19] Section 680-5.250(101) of the Iowa Administrative Code in effect on the date of the installation provided that "[t]he standards of 'Storage and Handling of Liquefied Petroleum Gas,' No. 58, 1979 edition of the National Fire Protection Association . . . shall be the rules governing liquefied petroleum gases in the state of Iowa."

[20] Under current Iowa law, the 1992 edition of NFPA 58 governs the storage and handling of propane and other LP-Gases in the state. Section 3-2.4.1(c) of the 1992 edition of NFPA 58 states: "Where physical damage to LP-Gas containers, or systems of which they are a part, from vehicles is a possibility, precautions shall be taken against such damage."

[21] Section 3-2.8.6 of the 1992 edition of NFPA 58 states, in part that, "[a]boveground piping shall be well supported and protected against physical damage."

an all-terrain vehicle (ATV) stored at the farm. Despite the regular exposure of the tank and its aboveground piping to potential damage from vehicles, neither the propane tank nor its piping were protected by a fence or any other physical barrier designed to prevent such damage. The lack of piping protection for the propane system at the farm allowed the ATV to crash into the pipes that ran from the tank to its vaporizers, breaking them and releasing the propane that ignited.[23]

4.1.2 Improper Size of Outlet Pipe from Excess Flow Valve FV3

The liquid line that ran from the tank to the vaporizers was equipped with an excess flow valve, which was designed to automatically close when the flow through the valve exceeded a predetermined rate -- the closing rating. This particular valve had a closing rating of approximately 200 gallons per minute. In the event of a complete break in the outlet pipe downstream from the excess flow valve, the valve should have closed and greatly reduced[24] the flow of propane from the broken pipe. When the ATV severed the liquid line, however, the excess flow valve failed to close because the flow capacity of the outlet piping system was less than the closing rating of the excess flow valve.

At this installation, the outlet piping downstream from the valve was too narrow for the valve installed in the tank.[25] If the pipe downstream from an excess flow valve is too narrow in

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[22] Two aboveground pipes (liquid and vapor lines) ran from the propane tank to its vaporizers. Aboveground piping also ran from the tank to the fueling truck point-of-transfer to the tank. See Figure 2, item 8.

[23] The National Fire Protection Association (NFPA) investigated and reported on this incident. NFPA determined, in part, that "[h]ad this installation been protected against vehicular traffic, the liquid lines would not have been damaged by the ATV, which began the tragic chain of events that led up to the death of the two fire fighters." Duval, Robert. *Fire Fighter Fatalities Albert City Iowa April 9, 1998*; National Fire Protection Association: Quincy, MA, 1999, 22.

[24] Even when an excess flow valve is activated, a small amount of fluid bleeds through a tiny hole in the valve. Consequently, installation of a shut-off valve immediately downstream from the excess-flow valve is required to stop all flow.

[25] The CSB has focused in this report on a specific flaw in the design of the liquid line to the vaporizers: that the diameter of the outlet pipe was too narrow for the excess flow valve installed in the tank. Alternative valve and pipe combinations (i.e., a smaller excess flow valve matched with the outlet pipe that was used) may have also prevented this incident or been more appropriate for this system. Thus, the CSB does not intend to imply that a larger outlet pipe to the vaporizers was the *only* possible alternative design for this particular installation. A complete discussion of possible alternative designs, however, is beyond the scope of this report.

diameter, flow through a severed line can be restricted so that it will not exceed the closing rating required for the valve to activate. Thus, an excess flow valve will generally not close if the pipe downstream is smaller in diameter than the valve, even if a complete break of the line occurs. For this reason, section 3135(a)(3) of NFPA 58 provided that "[t]he connections, or line, leading to or from any individual opening shall have greater capacity than the rated flow of the excess flow valve protecting the opening."[26]

At this installation, however, the piping downstream of the excess flow valve did not conform to this NFPA requirement. Specifically, shut-off valve A20, which was downstream from excess flow valve FV3, was fitted with two bushings that reduced the flow of propane by decreasing the diameter of piping in the line to approximately ¾ of an inch. In this incident, the break in the line occurred at the point where the second bushing connected to the ¾-inch outlet pipe to the vaporizers (see Figure 6). Following the break, the excess flow valve did not close because the flow of propane through the line was restricted by the reducer bushings to a rate below the closing rating of the valve.

A NASA laboratory, the Kennedy Space Center Materials Science Division, conducted tests on the excess flow valve which demonstrated that the valve closed properly when it was installed in accordance with the manufacturer's recommendations and that it did not close when attached to a ¾-inch inside-diameter pipe. Details and results of this reconstruction analysis are provided in Appendix B.

[26] Under current Iowa law, the 1992 edition of NFPA 58 governs the storage and handling of propane and other LP-Gases in the state. Section 2-3.7 of the 1992 edition contains language identical to section 3135(a)(3).

4.2 REGULATORY OVERSIGHT

4.2.1 Overview

The Iowa State Fire Marshal was (and remains) responsible for enforcing state regulations concerned with the "storage, transportation, handling and use of liquid petroleum gas."[27] Under Iowa law, the State Fire Marshal should have received a plan of the farm's propane tank storage and handling system before it was installed. The CSB's investigation revealed that the State Fire Marshal had no record of the propane system at the farm and that it was not installed in compliance with all NFPA 58 requirements adopted as Iowa law. Even if a plan had been submitted prior to the installation, however, the State Fire Marshal's Office probably would not have uncovered both deficiencies in the installation that contributed to the incident; that office did not have a program in place to adequately monitor or inspect large propane tank storage facilities.

4.2.2 State Regulatory Oversight

Under NFPA 58 and other relevant Iowa law, the State Fire Marshal should have received a plan of the farm's propane tank storage and handling system before it was installed. Section 1400 of the 1979 edition of NFPA 58 stated that "[p]lans for fixed (stationary) installations utilizing storage containers of over 2000 gallons individual water capacity . . . shall be submitted to the authority having jurisdiction before the installation is started." Iowa law, however, did not specifically designate which party -- the owner or the installer of a large propane tank facility -- was required to submit a plan to the "authority having jurisdiction," the State Fire Marshal. In this instance, one of the owners of the farm had no knowledge of the requirement to submit a plan. He believed that this was the obligation of the company that connected the tank to the

[27] *See* 5 Iowa Code Ann. §100.1(4)(c) (1998).

vaporizers. That company, in turn, maintained that it had no responsibility to submit a plan to the State Fire Marshal and that it was the tank owner's responsibility to do so. Clarification of Iowa law in this regard and communication of this information to interested parties would help eliminate such confusion. In the meantime, the State Fire Marshal estimated that "a great many tanks are installed without plans being sent in."[28]

As discussed above, the propane system at the farm did not comply with NFPA 58 as adopted by Iowa in two significant respects. First, aboveground piping that ran from the storage tank to the vaporizers was not protected from potential damage from vehicles. Second, the diameter of the outlet pipe downstream from an excess flow valve was too narrow, which prevented that valve from functioning properly.

If a plan of the propane system at the farm had been submitted to the State Fire Marshal as required in 1988, it is likely that the State Fire Marshal's Office would have noticed the lack of physical protection from vehicle damage. Since at least 1988, the State Fire Marshal has reviewed plans of propane systems for compliance with certain NFPA 58 requirements. According to the State Fire Marshal's Office, this "plan review" checks for "fencing, vehicle protection, and other items that can be determined from a site plan."[29] The State Fire Marshal stated that a plan for the farm's installation would have been checked for "aboveground piping protection and items visible on the drawings."[30]

Even if a plan had been submitted in 1988, however, the State Fire Marshal's plan review would not have uncovered the improper sizing of the piping from the excess flow valve. The State Fire Marshal acknowledged that a review of the plan for the propane system at the farm would probably not have detected the improper "sizing of excess flow valves and connecting piping."[31] Moreover, the State Fire Marshal explained that he lacked (and still lacks) the resources needed to conduct an inspection of each regulated propane system in the state for full compliance with Iowa law (NFPA 58). He employs one inspector on a part-time basis to handle LP-Gas *and* all other flammable liquids regulated by his office. He estimates that three full-time inspectors

[28] Marshal, Roy. Iowa State Fire Marshal. Correspondence to CSB, December 18, 1998.
[29] *Ibid.*
[30] *Ibid.* The State Fire Marshal explained that the Fire Prevention inspector assigned to review the plans receives training "in the area of LP gas and Flammable Liquids."

solely dedicated to LP-Gas matters would be required to effectively enforce NFPA 58 requirements.

4.3 DAMAGE TO LIQUID LINE

CSB investigators based the conclusion that the impact of the ATV broke off the liquid pipe at its connection to the shut-off valve on a number of factors. The piece of ¾-inch liquid pipe broken off was labeled A1 following the incident (see Figures 29 and 36 in Appendix B). As these figures illustrate, a bend was discovered in the A1 segment between the threads and the union (a coupling used to connect two segments of pipe). This bend indicates that this segment of A1 was subjected to a significant horizontally applied load before fracture occurred. Horizontal stress patterns identified on the edge of the A1 pipe segment that connected to the A20 valve also revealed that the pipe failed in a horizontal plane (see Figure 37, Appendix B). Had the A1 piece been completely connected to the A20 valve at the time of the explosion, these stress patterns would almost certainly have been twisted with a vertical orientation, not a horizontal one. Thus, the force required to produce these stress patterns most likely occurred when the ATV hit the liquid line. The direction of thread deformation on the A1 edge (Appendix B, Figures 36-39) also indicates that the pipe was subjected to a horizontally applied load such as that likely caused by the impact of the ATV.

In addition, the debris map in Appendix C illustrates that the A1 piece was discovered in the immediate area of the original tank location following the blast. The discovery of A1 at this location suggests that it was severed from the shut-off valve prior to the explosion. The shut-off valve, which had been connected to A1, was thrown a significant distance from its original location by the explosion (see Appendix C, item A20).

If the A1 piece were still connected to the shut-off valve at the time of the explosion, there would most likely be dents or other types of damage visible on the pipe surface similar to the damage

[31] *Ibid.*

observed on other pieces of debris. For example, the shut-off valve (A20) exhibited a number of abrasions that likely occurred as a result of the explosion. As Figure 29 in Appendix B shows, the A1 piece was not dented or damaged. Finally, eyewitness reports of fire under the north and west end of the tank following the impact of the ATV were consistent with a propane leak in the vicinity of the A20/A1 connection under the tank.

4.4 ALBERT CITY VOLUNTEER FIRE DEPARTMENT TRAINING

The Albert City Fire Department (department) is an all-volunteer force that covers a response area of 100 square miles and serves a population of 850.[32] Members of the department received some initial training, which varied depending upon each member's availability to attend specific training courses. Training topics included "personal safety, forcible entry, ventilation, fire apparatus, ladders, self-contained breathing apparatus, hose loads, streams and special hazards."[33] In addition, as discussed in sections 4.4.1-4.4.3 below, certain members of the department received some additional training on responding to LP-Gas leaks and fires. Fire fighters in this incident, however, had inadequate training on recognizing the potential for a BLEVE and appropriate response procedures.

4.4.1 National Propane Gas Association Training Materials

According to the Chief of the department, he and about 90 percent of the department's fire fighters had watched a videotape entitled *Handling LP-Gas Leaks and Fires*. Certain members of the department viewed the tape during a three-hour training session in September, 1997.

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[32] Duval, Robert. *Fire Fighter Fatalities Albert City Iowa April 9, 1998*; National Fire Protection Association: Quincy, MA, 1999, 8.

[33] *Propane Tank Explosion Results in the Death of Two Volunteer Fire Fighters, Hospitalization of Six Other Volunteer Fire Fighters and a Deputy Sheriff – Iowa*; Fire Fighter Fatality Investigation Report 98F-14; National Institute of Occupational Safety and Health, Fire Fighter Fatality and Investigation Program, http://www.cdc.gov/niosh/face9814.html (accessed April 1999).

The National Propane Gas Association (NPGA) produced the videotape. One of the recommendations in the videotape for responding to propane tank fires is that fire fighters should "approach the container from the sides and from upwind."[34] The videotape, however, does not warn fire fighters that fragments may be thrown in all directions when a BLEVE occurs, causing death and injury to responders approaching from the sides of the container.

The NPGA training guide accompanying its videotape, entitled *LP-Gas Fire Control and Hazmat Training Guide*, states: "should the container rupture, it can and will, most likely, travel in the direction it is pointed."[35] Although the NPGA mentions BLEVEs in another section of its guide, it does not explain that in a BLEVE, fragments can travel in all directions.

The NPGA recommendations could be interpreted by fire fighters to mean that staying away from the ends of a burning propane tank will protect them in the event of an explosion. In this incident, the Fire Chief reported that he relied on NPGA and other similar training guidelines and believed that avoiding the ends of the burning tank would protect fire fighters. Avoiding the ends of a tank does not provide protection when a BLEVE occurs.

4.4.2 Training By The Fire Service Institute, Iowa State University

In order to respond to a hazardous material release such as the one at the farm, the Albert City volunteer fire fighters should have received the training required by the Hazardous Waste Operations and Emergency Response law known as HAZWOPER.[36] The Fire Service Institute of Iowa State University provided HAZWOPER operations-level training for some members of the Albert City Volunteer Fire Department. The two deceased fire fighters and the Assistant Fire Chief successfully completed the twelve-hour, operations-level training course in March or April of 1996. According to the Institute, the Fire Chief did not complete operations-level training. Even if all of the members of the department had received the training offered by the Institute, however, this training would have been insufficient to prepare members of the department to

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[34] National Propane Gas Association. *Handling LP-Gas Leaks & Fires.* Video #0994. Lisle, Illinois, 1992.
[35] National Propane Gas Association. *LP-Gas Fire Control and Hazmat Training Guide*, Lisle, IL, 1991, 4.
[36] Iowa has adopted the federal HAZWOPER standard. For further information on the federal HAZWOPER training requirements, *see* 29 CFR § 1910.120 (q)(6).

properly respond to a potential BLEVE. The Fire Service Institute's student manual entitled *Iowa Hazardous Materials Operations*,[37] contained only basic information about BLEVEs.

In addition, first responders trained at the operations level are individuals who should respond in a defensive fashion. "Their function is to contain the release from a safe distance, keep it from spreading, and prevent exposures."[38] If members of the department had responded in a defensive fashion (see section 4.5 of this report), it is likely that the fatalities could have been prevented.

4.4.3 Guidance on Propane Tank Fires in *1996 North American Emergency Response Guidebook*

The *1996 North American Emergency Response Guidebook* is widely used by emergency responders and was carried by fire fighter response vehicles at this incident. The Chief of the department said that he did not consult the guidebook on the night of the incident, but that he was generally familiar with the propane fire response guidelines it contained. Had it been consulted, some of the recommendations in the guidebook could have prevented the fire fighter fatalities. For example, Guide Number 115, which addresses propane tank fires, recommends, in part, that responders to a massive fire "use unmanned hose holders or monitor nozzles" or, if this is not possible, to "withdraw from the area and let fire burn."[39]

On the other hand, one of the recommendations in the guidebook might have been misleading. Guide Number 115 recommends that responders "ALWAYS stay away from the ends of tanks."[40] As with the NPGA response guidelines discussed above, fire fighters could interpret this Department of Transportation (DOT) recommendation to mean that by avoiding the ends of the tank they would be safe. In a BLEVE such as the one in this incident, however, fragments from the explosion can travel in all directions from the tank. Avoiding the ends of the tank does not provide protection for responders when a BLEVE occurs. Because the guidebook was not

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[37] Ballard, David. *Iowa Hazardous Materials Operations*: *Student Manual*, Fire Service Institute, Iowa State University Extension: Ames, IO, 1996.
[38] 29 CFR 1910.120(q)(6)(ii).
[39] United States Dept. of Transportation. 1996 *North American Emergency Response Guidebook*, J. J. Keller & Associates, Inc.: Neehah, Wisconsin, 1996, 178-179.

consulted in responding to the fire at the farm, the CSB did not find that the potentially misleading DOT guideline contributed to causing the casualties in this incident.

4.5 ANALYSIS OF EMERGENCY RESPONSE

Fire fighter training material published by the International Fire Service Training Association (IFSTA)[41] include the following guidelines for responding to propane tank fires:

- Do not assume that the venting of propane from relief valves will prevent overpressurization and rupture of the tank;
- Apply large quantities of water to the tank. For large propane tanks, at least 500 gallons per minute is needed;
- If a flame is impinging on the tank, water must be applied directly to the impinged area in order to prevent a BLEVE;
- Water should be sprayed by use of an unmanned fire hose system; and
- If a continuous supply of water is not available, withdraw and isolate the area for ½ mile in all directions.

Fire fighters responding to this incident did not follow response guidelines such as those published by the IFSTA. Not following response guidelines such as these had the following consequences:

- Fire fighters did not spray water on the burning tank to try to prevent a BLEVE;[42] and
- Fire fighters were deployed too close to the tank. They did not withdraw and isolate for ½ mile as recommended by IFSTA. This allowed fragments from the exploding tank to strike and kill two fire fighters.

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[40] *Ibid.*

[41] International Fire Service Training Association. *Hazardous Materials for First Responders*, 1st ed.; Fire Protection Publications, Oklahoma State University: Stillwater, OK, 1990, 276-80.

[42] Fire fighters may not have recognized that even if they started to spray water on the tank, the inadequate water supply likely would have prevented them from effectively cooling the tank.

4.5.1 The Time Factor in Responding to the Scene of a Potential BLEVE

BLEVEs can take place rapidly when a fire is impinging on the surface of a non-fireproofed[43] propane tank above the liquid level of the tank. According to the American Petroleum Institute (API), this type of storage tank usually ruptures violently after 10-30 minutes of direct exposure to flame if water is not applied to cool the tank.[44] The API also notes that some tanks have ruptured after only 10 minutes of exposure to flame.[45] The quickness with which a BLEVE can occur is very important for fire fighters to consider when deciding how they will respond to a propane tank fire. If too much time has elapsed, the best action fire fighters can take may be to retreat to a safe distance. In this incident, only 18 minutes elapsed from the time of the 911 call until the BLEVE occurred, as shown in the table below:

Event	Time	Elapsed time
ATV strikes propane piping	11:00 pm[46]	
Leaking propane ignites	11:05 pm[47]	5 minutes
Notification to 911 operator	11:10 pm	5 minutes
Albert City Volunteer Fire Department Dispatched to Scene	11:11 pm	1 minute
Fire fighters arrive at the scene	11:21 pm	10 minutes
BLEVE occurs	11:28 pm	7 minutes
		28 minutes

4.5.2 Deployment of Personnel When Fighting a Propane Tank Fire

Some propane storage tanks, such as the one involved in this incident, are horizontal in shape and therefore have distinct ends and sides (see Figure 3). The Albert City Fire Chief believed

[43] Use of fireproofing materials on storage tanks does not eliminate the possibility of a BLEVE, but it can increase the time that elapses prior to a BLEVE taking place. For additional information, *see* Duval, Robert. *Fire Fighter Fatalities Albert City Iowa April 9, 1998*; National Fire Protection Association: Quincy, MA, 1999, 21-22.
[44] American Petroleum Institute. *Fire-Protection Considerations for the Design and Operation of Liquefied Petroleum Gas (LPG) Storage Facilities*; API Publication 2510A, 1st ed.; Washington, DC, 1989, 31.
[45] *Ibid.*
[46] This is an estimate based on witness accounts.
[47] This is an estimate based on witness accounts.

that fire fighters would be safe if they avoided the areas extending from the ends of the tank. Based on the training that he had received, the Fire Chief also thought that, in the event of an explosion, the tank would rupture and throw fragments from the ends. He did not think that fragments would be thrown from the sides of the tank. A BLEVE, however, can disperse tank fragments in all directions.[48] Thus, even if circumstances (i.e., water supply and time factors) allow for the application of water to a tank in an effort to prevent a BLEVE, water should be sprayed by use of an unmanned fire hose system as recommended by the IFSTA and the *1996 North American Emergency Response Guidebook.*

4.6 ALTERNATIVE SCENARIO

The CSB received a comment theorizing that the impact of the ATV caused a partial break[49] in the vapor line to the vaporizers, at a location near the manway on the top of the tank. This damage, the comment asserted, in turn caused a leak of propane that ignited and directed flame downward onto the top of the tank. CSB investigators found no evidence to support the theory that flame from this vapor line source contributed to causing the BLEVE.

NASA investigators found no conclusive evidence that the vapor line piping in the vicinity of the manway was partially broken or severed by the impact of the ATV. In addition, none of the eyewitnesses observed flame being directed downward onto the top of the tank. Finally, a certified fire investigator with the Department of the Treasury's Bureau of Alcohol, Tobacco and Firearms examined the tank shell. He did not find any flame pattern markings on the top of the tank which indicated that a flame had been directed downward onto the top portion of the tank.

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[48] For a discussion of recent research on the BLEVE hazards of small containers, *see* Hildebrand, M.S.; Noll, G.G. *Propane Emergencies*; Red Hat Publishing Company, Inc.: Chester, MD, 1999, 136-137.

[49] An excess flow valve protected the vapor line that was damaged by the ATV. If that line was completely severed by the impact of the ATV, that excess flow valve would have been activated, thus virtually shutting off the flow of propane in that line. The comment assumed that the impact of the ATV did not cause a complete break anywhere in the line and that the valve was not activated. It is possible that the ATV did completely sever the vapor line, thus activating the excess flow valve on that line. The CSB, however, did not conclusively determine whether the vapor line was severed completely prior to the explosion.

4.7 ROOT AND CONTRIBUTING CAUSES

Root Causes

1. Protection for aboveground piping was inadequate.

Two aboveground pipes (liquid and vapor lines) that ran from the propane storage tank to its vaporizers were not protected from potential physical damage from vehicles. Lack of piping protection allowed a vehicle to crash into these pipes, breaking them and releasing the propane that ignited.

2. The diameter of the pipe downstream from an excess flow valve was too narrow, which prevented the valve from functioning properly.

An excess flow valve that was designed to stop the flow of all but an extremely small amount of liquid propane in the event of a severed line did not function because the diameter of the pipe downstream from the valve was too narrow to allow the valve to activate. Post-incident tests of the valve showed that it would have operated as designed if the pipe downstream had been the proper size. A functioning excess flow valve on the liquid line would have greatly reduced the severity of the fire that engulfed the tank. This likely would have prevented the BLEVE.

3. Fire fighter training for responding to BLEVEs was inadequate.

Some training materials provided to the fire fighters led them to believe that they would be protected from a propane tank explosion by positioning themselves to the sides of the tank and by avoiding the areas extending from the two ends of the tank. As a consequence, fire fighters were positioned too close to the sides of the burning propane storage tank when it exploded. Fire fighters did not adequately recognize the potential for a BLEVE and that a BLEVE can scatter tank fragments in all directions. In this incident, flying fragments from the explosion killed two fire fighters located approximately 100 feet from the side of the tank.

Contributing Cause

The State Fire Marshal did not detect deficiencies in the design and installation of the propane storage facility.

Under Iowa law, the State Fire Marshal should have received a plan of the farm's propane system prior to its installation in 1988. The State Fire Marshal had no record of the farm's system, however. Iowa law did not specifically designate which party -- the owner or the installer of a large propane tank facility -- was required to notify the State Fire Marshal. In addition, the State Fire Marshal did not have a program in place to adequately monitor or inspect large propane storage facilities.